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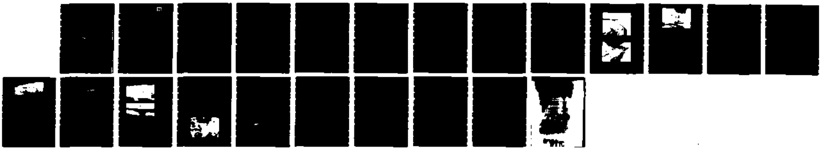

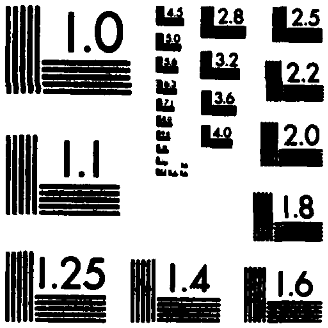

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Special Report 84-13

May 1984

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Performance of the Allegheny River ice control structure, 1983

David Deck and Gordon Gooch

Prepared for
U.S. ARMY ENGINEER DISTRICT, PITTSBURGH

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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Oil City, Pennsylvania, is at the confluence of the Allegheny River and Oil Creek. The business district is located in the flood plain, and ice jam flooding has been a persistent problem. A floating ice control structure was installed on the Allegheny River prior to the 1983 ice season. The structure was a steel pontoon ice boom located upstream of Oil City and was used to encourage early formation of an ice cover at this location. This would suppress prolonged frazil ice generation, which in the past led to a massive freezeup jam downstream. This accumulation would prevent the discharge of ice from Oil Creek

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20. Abstract (cont'd)

during breakup, when ice jam flooding would occur. The performance of the structure during its first year is documented here. Oil City escaped ice jam flooding during the winter of 1983.

PREFACE

This report was prepared by David Deck, Research Hydraulic Engineer, and Gordon Gooch, Civil Engineering Technician, Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The study was funded by the U.S. Army Engineer District, Pittsburgh. The report was technically reviewed by Dr. R.L. Gerard of the University of Edmonton, Alberta, Canada, and Dr. H.T. Shen of Clarkson College of Technology, Potsdam, New York.

CONTENTS

ILLUSTRATIONS

PERFORMANCE OF THE ALLEGHENY RIVER ICE CONTROL STRUCTURE, 1983

David Deck and Gordon Gooch

INTRODUCTION

The performance of a floating ice control structure (ICS) on the Allegheny River at Oil City, Pennsylvania, was monitored during the 1982-83 winter. The intent of the structure was to control the river ice during formation by forming an ice cover upstream of Oil City; this would prevent excessive frazil deposition downstream, which in past years has led to ice jam flooding. Deck and Gooch (1981) described the area and its ice jam flooding problem in detail.

The Oil City business district is located on a flood plain at the confluence of Oil Creek and the Allegheny River (Fig. 1). The natural river ice cover begins to accumulate approximately 3.5 km downstream of the city, and a continuous, stable cover can extend as much as 45 km upstream on the Allegheny River and 25 km on Oil Creek. The ice on both the creek and the river consists almost entirely of frazil ice. The freezeup jam is a hanging frazil dam that restricts up to 60% of the cross-sectional flow area. This accumulation is more than 5 m thick in some locations. Figure 2 shows a typical January or February scene at Oil City.

The Oil City region generally has little snow cover, so the runoff required for a rapid breakup of the ice cover primarily depends on a rainfall of 10 mm or so. Oil Creek responds quickly to this runoff, and its ice breaks up and runs to the river (Fig. 3). The Allegheny River takes much longer to respond, and hence the ice in the Oil City area is still stable at this time. This prevents the creek from discharging its ice. The Oil Creek ice consequently jams and produces overbank flooding. This event has occurred, on average, about every other year since 1950. Some $4,000,000 in damages resulted from the 1982 flood alone (Fig. 4).

It was proposed to Oil City officials that a floating structure be installed upstream of the confluence to control the ice formation, keeping the

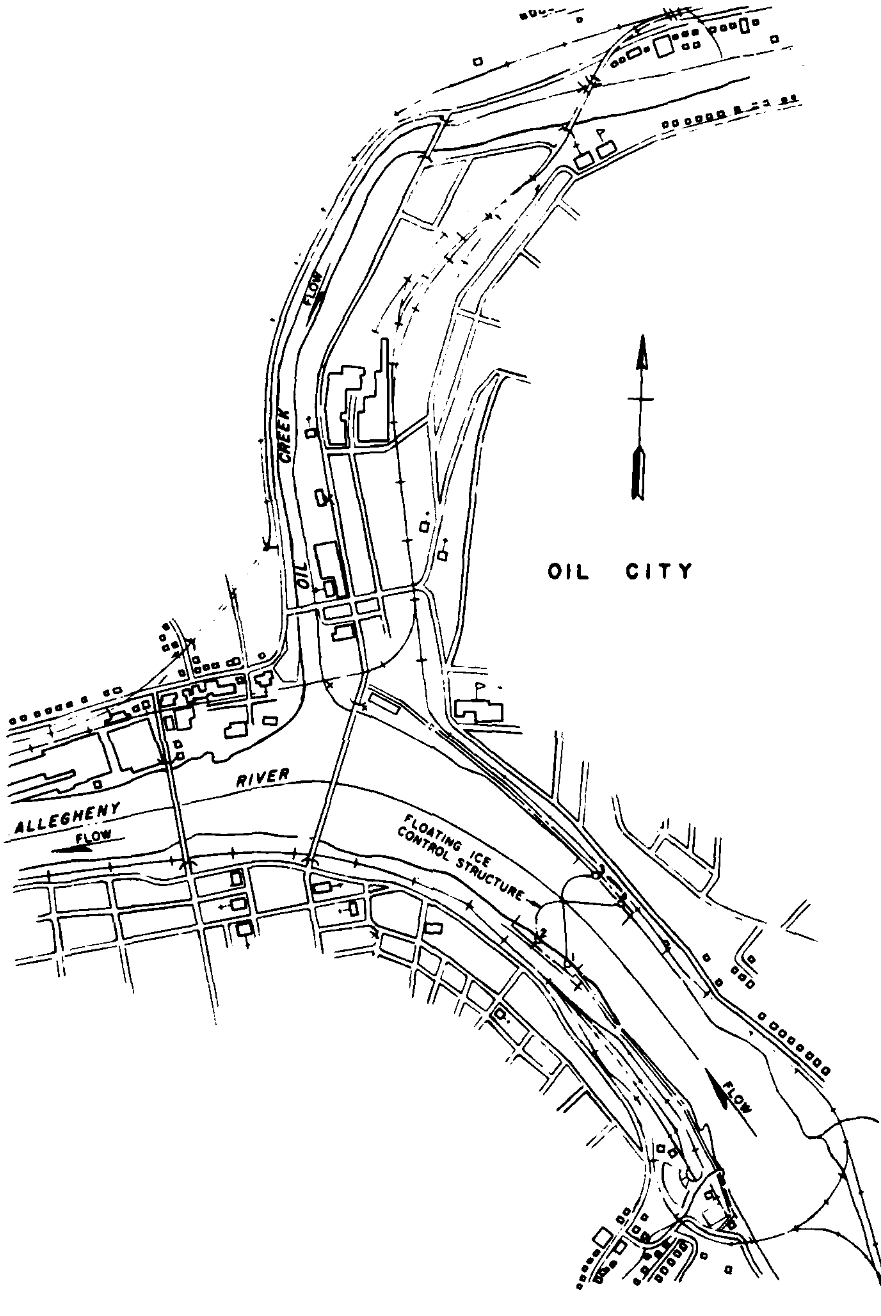


Figure 1. Plan view of Oil City.

Figure 2. Typical freezeup before ice control structures were built.

Figure 3. Oil Creek ice jammed at the confluence during breakup.

Figure 4. Results of an ice jam.

confluence area of the streams open and alleviating the ice jam flooding. The configuration, design load, and general design criteria for the ICS were furnished by CRREL to the U.S. Army Engineer District, Pittsburgh. They developed the anchor and detailed structure design and awarded contracts to fabricate and install the structure prior to the 1982-83 winter. The cost of these contracts was about $650,000. The ICS was constructed under the authority of Section 205 of the 1948 Flood Control Act. This report addresses the structure's performance during its first winter.

STRUCTURE AND SITE DESCRIPTION

The structure is an ice boom consisting of 20 floating steel pontoons attached by chain to a 60-mm-diameter, 6x19 wire rope. The pontoons are 613 cm long, 91 cm wide and 40 cm deep. Two spans of 77 m each are used to cross the river. The Allegheny is being considered for designation as a wild and scenic river; this would involve restrictions that would have made it difficult to anchor the structure to the streambed. Therefore, four shore anchors are used to eliminate any stream alterations (Fig. 5). Four wire ropes are attached to each anchor and joined at a junction plate at the approximate centerline of the river. Floats support the weight of this junction plate and the two wire ropes to which the pontoons are attached. A tension link with a calibrated strain gauge, developed and described by Perham (1974), was

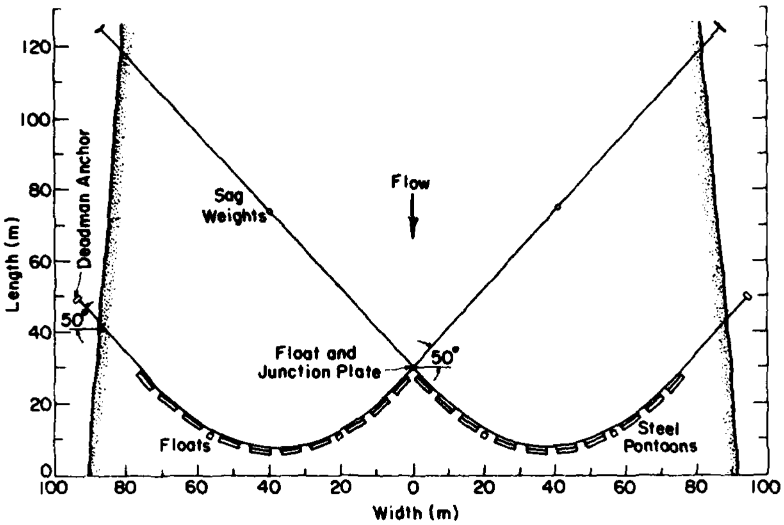


Figure 5. Detailed plan of the Allegheny River ice control structure.

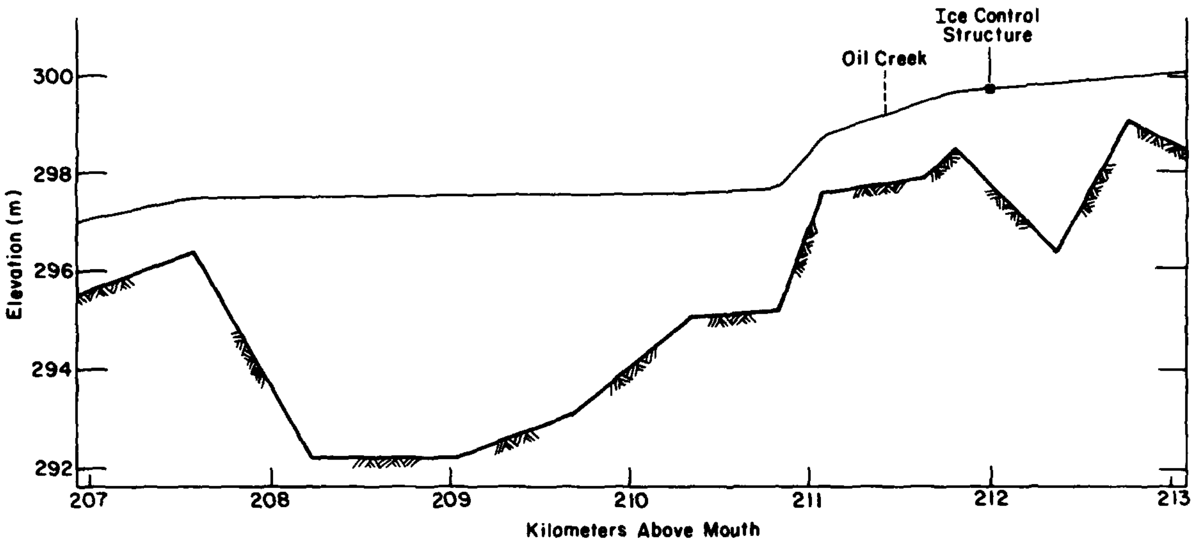


Figure 6. Bed and water surface profiles.

installed on the left bank between shore anchor #2 and the wire rope. This device monitored force levels during the ice season.

The ICS was located 0.5 km upstream of the mouth of Oil Creek at the downstream end of a relatively deep pool in the river (Fig. 6). The pool's reach is about 500 m, the mean depth is 2 m, and the mean width is 160 m. Kinzua Dam, an Army Corps of Engineers flood control dam, is located 100 km upstream of the site and can control about 50% of the river flow at Oil City.

RIVER ICE CONTROL

The upper reach of the Allegheny River is a series of scenic riffles and pools. During the winter months, when a cold air mass pushes into the Oil City area, air temperatures are in the range of -20° to -12°C. These air temperatures quickly supercool the water, and large quantities of frazil ice are produced. Our field measurements in 1980 indicated that 1.9×10^5 m^3 day^{-1} of frazil ice is transported by the river to the Oil City river reach. A large, deep dredged pool below the city allows the frazil slush to arch or bridge from bank to bank and form the initial stable ice cover. This natural ice arch occurs 3.5 km downstream of the city.

The intent of the ICS is to encourage a stable ice cover to form upstream of where the creek enters the river. This would suppress further frazil generation, keep the confluence area relatively ice free, and allow the creek ice to discharge into the river during breakup.

The Allegheny River flow conditions at the site are unfavorable for the formation of a stable ice cover. The mean winter river flow is generally about 200 m^3 s^{-1}. The corresponding mean values of velocity and flow depth are about 0.62 m s^{-1} and 2.0 m, and the associated Froude number F_r is 0.14.

It was therefore proposed in 1982 that Kinzua Dam be used to reduce the flow during freezeup to allow a stable cover to form quickly behind the ICS. Initially it is intended that the flow be reduced to about 70 m^3 s^{-1} in this way during freezeup. This would yield a mean velocity of 0.35 m s^{-1}, a mean flow depth of 1.65 m, and an F_r of 0.09. A stable ice cover should readily form under these conditions.

1982-83 WINTER RESULTS

Freezeup

Freezing air temperatures had lowered the Allegheny River water temperature to 0.5°C by 17 January. The air temperature in the early morning of the 18th fell to -12°C at Oil City. This cooled the river enough to generate the first frazil ice of the season in the upper reaches of the river. Frazil floes began accumulating behind the ICS before sunrise, with the cover progressing outward from the banks, continually developing small shear walls parallel to the flow. At 0700 hrs there remained a channel about 40 m wide at the center of the boom, where frazil continued to flow freely over the

Figure 7. Ice cover formed behind the ice control structure.

boom. The flotation characteristics of the pontoons, especially the six spanning the center of the river, were such that their upstream faces were submerged. This allowed the ice floes to pass over them easily. This problem will be discussed further in the next section.

From 0700 on, the ice cover formed more as a natural one would. The large number of frazil floes passing through the opening were continually compressed and thickened until they developed enough internal strength to arch or bridge the opening. This occurred at 1300 hrs on the 18th. The cover then grew very quickly upstream over the full 500-m pool (Fig. 7).

The river reach immediately upstream of this pool is relatively shallow and has a high flow velocity, which prevents a stable ice cover from forming over it. The downstream ice had to thicken to raise this water level enough to allow the ice to continue to grow upstream. The downstream ice thickened from the shoving and collapse of the frazil floes on the surface. Observations of the accumulating ice indicated that the shoving and thickening extended from the boom throughout the entire length of the pool. This was an iterative process that continued until 1700 hrs on 20 January, when a sufficient thickness and length of stable ice developed in the pool to raise the water level more than 0.8 m. This rise, measured 750 m upstream of the ICS, allowed the ice cover to grow upstream through this critical reach up to a smaller pool, where the ice cover progression continued.

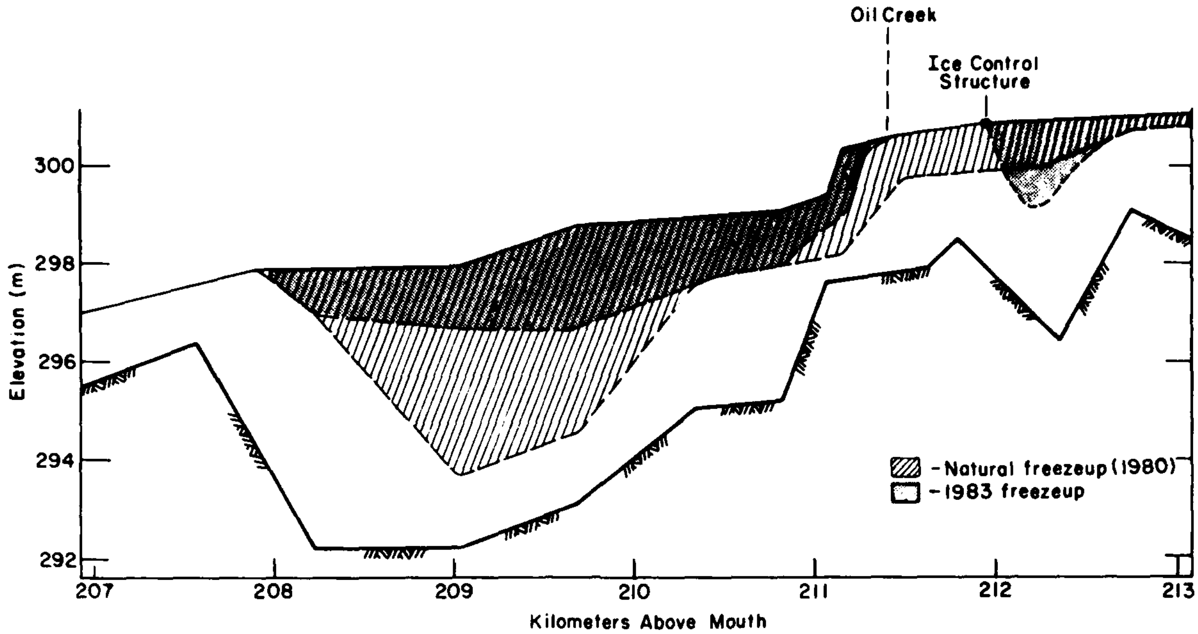


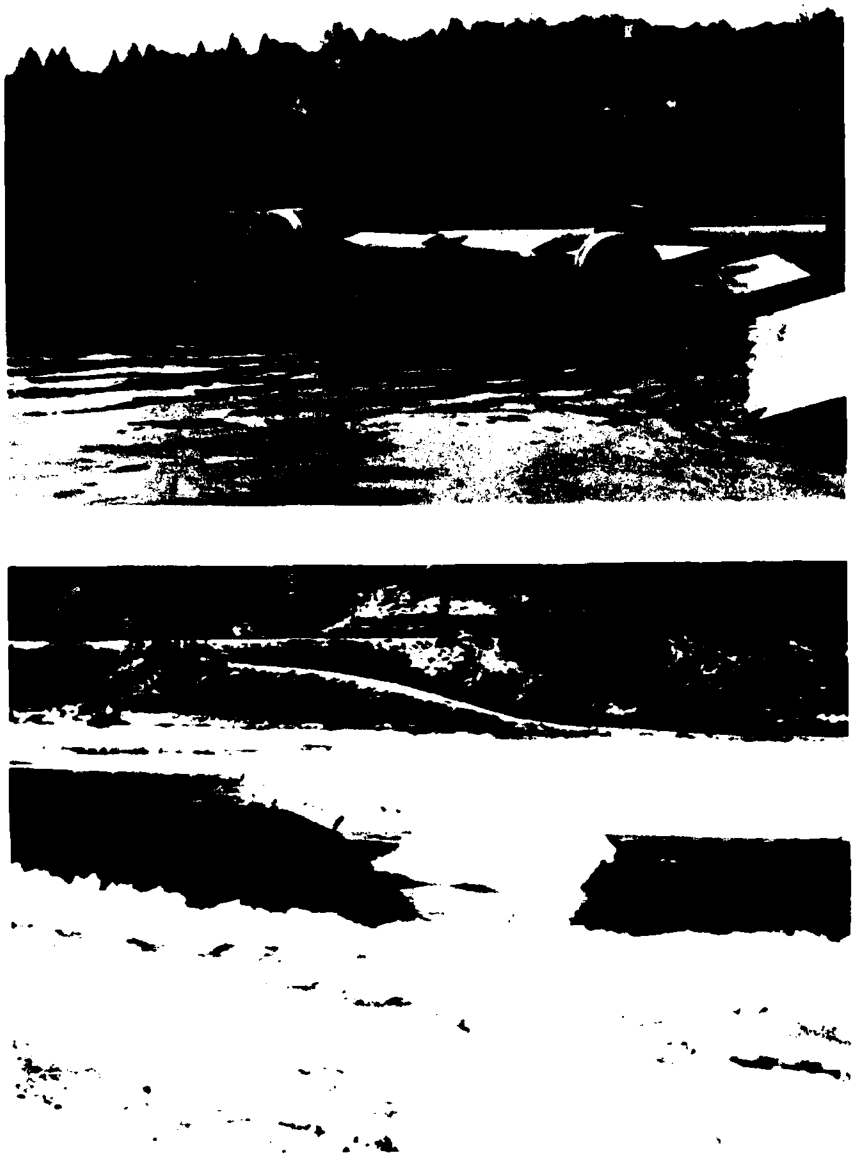
Figure 8. Bed and ice thickness profiles.

By the morning of 21 January the stable ice extended for 2 km upstream of the ice boom. The Allegheny continued to generate ice until about 1100 hrs. Another 0.5 km of ice had collected by this time, giving a total reach of 2.5 km of stable ice behind the ICS.

The amount of accumulated frazil ice at Oil City downstream of the ICS was 50% less than the natural freezeup amounts of prior years. Figure 8 compares the 1983 ice accumulation to the natural event documented in 1980. The natural freezeup had been used with the observed flow and water levels to calibrate the HEC-2 backwater model with the ice routine (U.S. Army Corps of Engineers 1979). The original calibration for open water was provided by the Pittsburgh District. The short, two-day duration of stable ice after the 1983 freezeup prevented ice thickness measurements from being made. Therefore, site observations of surface ice conditions, water levels, and flow were used to predict the accumulated thickness with HEC-2.

Pontoon flotation problem

The pontoons of the Allegheny River ICS did eventually encourage a stable cover of frazil ice to form, although they did not function as well as intended. The original design load provided by CRREL was more than doubled by the Pittsburgh District to prevent any possible failure of the substructure. This added substantial weight, for which the floats and pontoons were



a. In open water.

b. In ice.

Figure 9. Submergence of pontoons.

not adjusted. The additional weight of the substructure was too great for the four floats provided to support the wire rope. Furthermore, the junction plate float did little because it was too far from the junction plate. Essentially the entire wire rope substructure rested near or at the streambed. This greatly tilted or submerged the upstream faces of the pontoons at numerous locations. The top of the upstream faces ranged from 11 cm above the water surface to 10 cm below. More than half of the pontoons had this side below or almost even with the water surface (Fig. 9).

Frazil pans and slush rode up and over the submerged pontoons. It was clear from the freezeup observations that the center pontoons behaved almost as if they were neutrally buoyant. Small frazil floes easily rode up these pontoons, which would then completely submerge. Also, the shoving during the thickening process caused large quantities of ice to discharge over the structure. The force measurements confirm that the pontoons did little to stop this. Indeed the force level approached zero at times when the floating structure was submerged.

Breakup

Above-freezing air temperatures and light rain persisted in the catchment from 22 to 24 January. Although the majority of the Allegheny ice simply rotted in place, a series of small ice runs did occur during a five-hour period on the evening of the 24th. Occasional ice floes arriving from upriver aided in slowly moving out the rotted ice left behind the ICS. The forces exerted on the ICS during this period of dynamic ice were measured and recorded. The entire Oil Creek ice cover rotted in place. Oil City was not flooded during the 1983 ice season.

ICE FORCE MEASUREMENTS

A tension link with a strain gauge was installed between the connecting point on anchor #2 and the corresponding wire rope (Fig. 10). This allowed

Figure 10. Tension link.

the forces applied to the left span of the structure to be monitored during the ice season. The instrument was calibrated over the range of 0 to 1330 kN at 133-kN intervals. This range was used to assure that any unexpected peak loads would be recorded.

To correlate the measured tension with the resultant ice force in the direction of flow, it was assumed that the loading was uniform and therefore the wire rope developed a parabolic shape. Under this condition the maximum tension T_{max} at the fixed end of a parabola is

$$T_{max} = \frac{1}{2} F_i \left(1 + \frac{a^2}{16f^2}\right)^{0.5} \qquad (1)$$

where

F_i = resultant ice force (kN)

a = span (m)

f = horizontal sag (m).

The span and sag of the Allegheny River ICS were 77 and 23 m, respectively. This gives

$$T_{max} = 0.65 \; F_i \; . \qquad (2)$$

All ice forces reported here are based on eq 2.

Freezeup forces

The ice force history during freezeup is recorded in Figure 11. The ice cover was very unstable during formation, particularly for the first 18

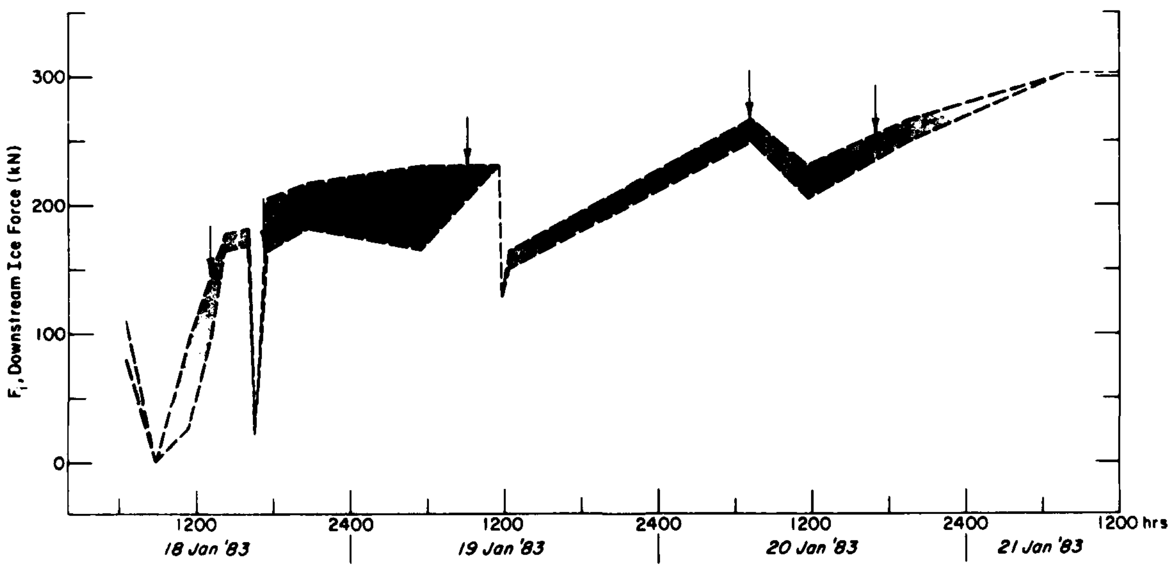


Figure 11. Freezeup ice forces (shading depicts the range of loads; arrows show the time of arching).

hours, and the ice force was very variable. Point force measurements are therefore difficult to depict. Instead only the range of loading has been shown. Much of the instability was due to the inefficiency of the pontoons in collecting the frazil floes and slush.

The ice cover arched for the first time at 1300 hours on the 18th and quickly progressed upstream over the length of the pool. As would be expected, the force levels increased as more ice collected. The force continued its upward trend after the first arch due to thickening and minor shoves and reached a maximum of 182 kN. A large shove moved ice over the structure at 1600 hours, and the forces dropped to 22 kN as the pontoons submerged. The ice arched again at 1710, and as the ice shoved and thickened to raise the upstream river stage, the forces increased to a peak of 231 kN. A large shove at 2000 again put ice over the submerged structure. The quantity of ice discharged this time was less than the previous amount, although the cover remained unstable until it arched again at 0900 on the 19th. Prior to this third arch, a small open lead had remained at the center of the river, but a considerable amount of ice had remained behind the ICS and more had continued to collect. Also, the frazil run had significantly slowed down until it again increased during the early morning hours. The majority of the frazil generation occurred in the upper river reach at night and arrived at the ICS during the day. At about 1200 on the 19th the entire ice sheet moved, and about half a kilometer of ice passed over the structure; after about 15 minutes the mass stopped and the ice sheet stabilized. A fourth arch formed at 0700 on the 20th. The fifth and final arch was established at 1700 on 20 January, when the frazil ice accumulation was thick and long enough to achieve the stage rise upstream required for further ice progression. The cover behind the ICS was then stable and remained so until breakup. The ice force peaked at 0700 on 21 January, reaching 302 kN (corresponding to a uniform distributed load of 3920 N m^{-1}), and it remained in a steady state until the ice run just before 1700 on 24 January.

Breakup forces

The ice force history during the five-hour ice run on 24 January is recorded in Figure 12. The peak force during breakup was lower than the freezeup value, although the mean force levels were similar.

Just before 1700 hours the first ice movement occurred, submerging the ICS and reducing the force level to zero. The forces applied to the ICS dur-

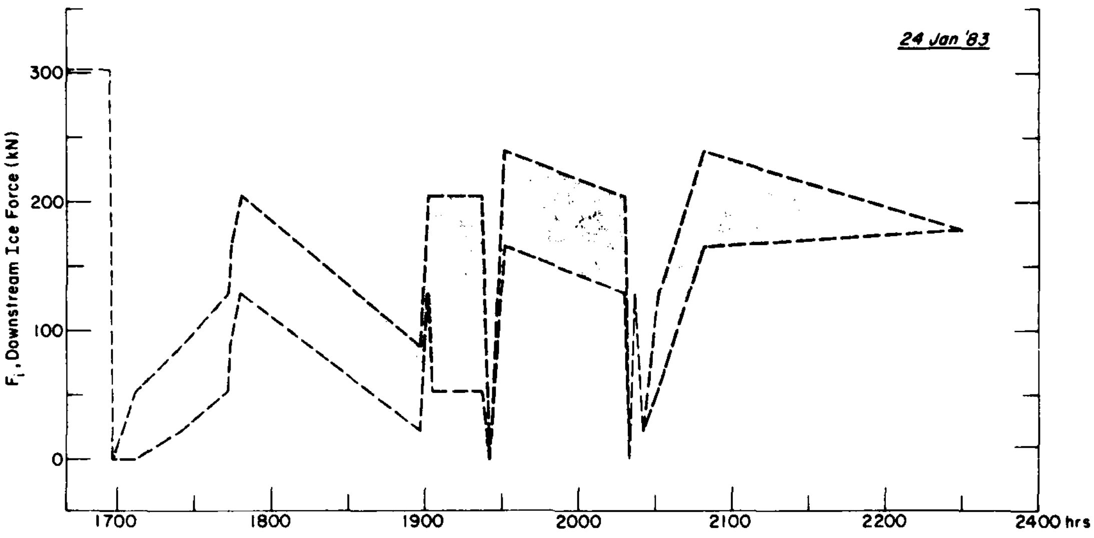


Figure 12. Breakup ice forces (shading depicts the range of loads).

ing breakup were erratic as the pontoons repeatedly moved up into and down out of the flow of ice. Zero readings occurred twice more, at 1925 and 2020, while the peak ice force reached 240 kN, corresponding to a uniform distributed load of about 3120 N m^{-1}.

DISCUSSION AND CONCLUSIONS

The Allegheny River ICS at Oil City was quite successful during the 1983 ice season, despite some problems that are to be expected in the first year in a unique application. The goal of forming a stable ice cover from frazil floes and slush was achieved, but the duration of this event must be shortened by improving the flotation of the pontoons. Further reduction of the downstream frazil deposition is essential during future ice seasons; modification of the structure should accomplish this.

The Allegheny River flow must continue to be controlled during the freezeup period. We recommend that Kinzua Dam incorporate this into its yearly operational schedule. A controlled flow of about 70 m^3 s^{-1} at Oil City should be maintained during frazil generation periods until a stable ice cover extends at least 3 km upstream of the ICS. Even with Kinzua Dam releasing the minimum discharge required for riparian rights (about 15 m^3 s^{-1}), there may be times when the flow at Oil City exceeds 70 m^3 s^{-1}. A practical guideline for Kinzua Dam might be to reduce its release to a minimum during freezeup. After a stable ice cover forms, it could then go back to a normal

operation. The period of ice formation in the reach of river and creek critical to Oil City generally lasts for only two to four days.

The flotation characteristics of the pontoons were inadequate for accumulating ice rapidly. The fact that a stable ice cover was still formed indicates the potential for success in controlling the river freezeup and alleviating the ice jam flooding at Oil City. There are two alternatives for improving the flotation of the pontoons: either replace the existing pontoons with larger ones or provide additional floats to support the weight of the substructure. The U.S. Army Engineer District, Pittsburgh, chose to provide additional floats. They designed these and awarded a fabrication contract; the floats were built during the summer of 1983 and installed in the fall.

The 1983 winter was relatively mild, with the mean monthly air temperature during January about 2°C above the long-term average. However, it only requires two or three days of extremely low temperatures for enough frazil to form to lead to a freezeup jam at Oil City. This happened during 18-21 January 1983. If more frazil had been generated in the upper river reaches, it would have only continued to deposit at the leading edge of the stable ice cover behind the ICS. The accumulated mass of frazil in the project's river reach would not have been increased with extended low air temperatures; only the solid ice thickness would have increased.

The natural freezeup and breakup at Oil City has been monitored each winter ice season since January 1980. The first ice of the season is frazil generated in Oil Creek. This ice is transported freely out into the river, as there are no areas capable of naturally arching or bridging. The frazil continues to flow into the river until the river also begins to generate frazil. When the concentration of floating ice in the river is high enough, it arches downstream of the city. As this reach develops a stable cover by shoving and thickening, it restricts 60% of the cross-sectional flow area, increasing the creek stage by 1-2 m, allowing a stable ice cover to extend up the creek. This process was delayed by one full day during the January 1983 freezeup and that the ice cover length that forms in the creek was reduced by some 8 km. This decreased the threat of ice jam flooding in Oil City tremendously.

Several winter seasons will be required to make the performance of the Allegheny River ICS acceptable. The 1983 results proved that frazil ice can be controlled in the river reach at Oil City. In addition to the river

structure, an experimental ICS was installed in December 1983 in a new location on Oil Creek to control frazil generation. The winter of 1984 provided additional answers and will be analyzed in a future report.

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